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A STUDY OF THE SITE VIBRATION CHARACTERISTICS FOR THE FECHIN INSTITUTE IN TAOS, NEW MEXICO

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Marcie S.H. Kam
Brian Hoerst
Phillip J. Cornwell
Charles R. Farrar
Isaac F. Salazar

Los Alamos
National Laboratory
Los Alamos, New Mexico 87545

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BY

Marcie S.H. Kam, Brian Hoerst, Phillip J. Cornwell, Charles R. Farrar
Engineering Sciences and Applications Division
Engineering Analysis Group
Los Alamos National Laboratory

Revised June, 1998, by Isaac F. Salazar and Phillip J. Cornwell

ABSTRACT

Members of the Engineering Analysis Group at Los Alamos National Laboratory were asked to conduct a vibration study of the Fechin Institute. Representatives of this museum and historical site suspect that its adobe structures are sustaining crack damage from excessive ground vibrations caused by construction traffic on an adjacent gravel road. The equipment used, test procedures, results obtained, and limitations of these results are discussed in this report. The conclusion of this study is that it can be shown definitively that the adobe structures are being subjected to increased vibration levels resulting from the monitored traffic.

The primary limitation of this study is that there has been no testing performed to determine an upper bound to the levels of excitation caused by trucks larger than a medium sized delivery vehicle. The vibrations believed to have caused the onset of damage were large construction and earth-moving vehicles, some carrying heavy loads such as concrete. Also, no studies have been undertaken to determine allowable vibration levels for these adobe structures. Such studies are beyond the scope of work that can be completed as part of an unfunded community outreach activity. Without such a study, it is difficult to quantify the damaging effects of the measured traffic-induced ground vibration.

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INTRODUCTION

Members of the Engineering Analysis Group at Los Alamos National Laboratory were asked to conduct a vibration analysis of the Fechin Institute at Taos, New Mexico. The Fechin Institute is a historic site consisting of adobe structures built in the 1920's and a recently constructed gift shop. Located directly east of the Institute is the Fechin Inn, an 85 room hotel constucted in 1996. The site of the Institute and Inn is located next to Kit Carson Park on Paseo Del Pueblo Norte. The primary concern that motivated this study is the cracking that has been observed in the adobe walls and concrete foundation of the main structure of the Institute. Representatives of the Institute first noted the cracks after the construction of the Fechin Inn had commenced. The cracking is described in detail in a reports prepared by Delapp Engineering Corporation and is enclosed in Appendix A. Proposed repair plans have been presented in a study conducted by Gordon and Associates and is also found in Appendix A. A potential cause of the cracks is vibrations and the resulting soil compaction caused by construction vehicles used during the construction of the Fechin Inn.

The procedure used to study the vibration problem consisted of first performing laboratory tests under controlled conditions to establish the electrical noise levels in the vibration measurement system. These tests identify the lowest level vibrations the sensors are capable of monitoring. Then measurements of the background vibration and vibration levels caused by measured-force impact tests and traffic excitation were then measured at the site. The equipment used, testing procedures, results obtained, and limitations of these results are summarized below.

II. EXPERIMENTS

A. Description of the test site

The Fechin Institute is a traditional adobe brick house on a stone foundation; additional wings on the north and south sides of the Institute were laid on concrete foundations. An inspection conducted by Gordan and Associates on February 14, 1997 (see Appendix A) suggests that the cracks found in parts of the house "became overt during the construction of the Fechin Inn" behind the original Fechin house. It was suggested that construction traffic could have created excessive vibration levels that caused the settling of the soil supporting the foundation.

B. Electronic Noise Test

Typically, background vibration levels on site will be greater than those found in the lab, since the system is not isolated from ambient vibrations caused by the wind and other sources. Checking this system noise level determines a floor value above which vibration data taken by the equipment can be considered meaningful. The noise level in the lab is expected to be very low, and it is important to quantify this noise level for determining the significance of other measurements made by the same equipment.

1. Experimental equipment and procedure

The test equipment used in this study and shown in Figures 1 and 2 consisted of a Hewlett-Packard (HP) 3566A dynamic data acquisition system including a model 35650 mainframe, 35653A source module, 4 35653A 8-channel input modules which provided power for accelerometers and performed the analog to digital conversion of accelerometer signals, and a 35651C signal processing module that performed the needed Fast Fourier Transform calculations. A Toshiba Tecra 700CT Laptop was used for data storage and as a platform for the HP software that controls the data acquisition system.

The system samples the analog signal from PCB model 336C piezoelectric accelerometers at approximately 32.8 kHz (regardless of the frequency range being analyzed), passes the signal through an analog anti-aliassing filter, digitizes it, then passes the data though a digital anti-aliassing filter with the cutoff frequency based upon the Nyquist frequency for the specified sampling parameters. The signal is then decimated based on the particular sampling parameters.

The data acquisition system was set up to measure acceleration-time histories, force-time histories, and calculate the Power Spectra of these time histories. Power Spectral Densities are functions which are a standard format for comparing vibration amplitude levels as a function of frequency. Testing parameters were specified as 10 averages of 4 second time windows discretized with 1024 samples; the spectra were calculated for a frequency range of 0-100 Hz. A Hanning window was applied to the time signals from the ambient data; and a force-exponential window was applied to the impact-excitation data, both to minimize leakage. The 1024 time sample yield 512 spectral points, but because of the rolloff in the anti-aliassing filters, only 401 spectral points are displayed.

The dynamic range for data acquisition was set using the autoranging feature in the HP software. This feature samples the signal during an initial interval and adjusts the dynamic range such that overloads will not occur thus maximizing the signal-to-noise ratio. The system does not accurately measure DC response; hence the first spectral points do not represent the true low-frequency response.

A PCB model 336C integrated circuit piezoelectric accelerometer was used for vibration measurements. This accelerometer has a nominal sensitivity of 1 V/g, an operating frequency range of about 1 - 1000 Hz, and an amplitude range of +/- 4 g's. A 100-foot length of coaxial cable connected to a short length of MicroDot cable was used to connect the accelerometer to the input module.

All data reported in this study were obtained using the equipment listed above. Sampling parameters for all measurements were the same. Spectral responses beyond the specified range of 100 Hz were not considered of interest in this study.

The ambient noise tests in the lab were performed by suspending a 3 inch aluminum cube about 1 foot from the ground using a 4 foot length of 0.375 inch diameter surgical tubing from a tripod. A total of 10 time measurements were taken and the data averaged. On site ambient noise tests were conducted in the same manner with the tripod on a flat portion of the soil next to the house. The setup is shown in Figure 3.

For the soil vibration measurements, an 18-inch-long, fully threaded 0.375-inch diameter steel rod was attached to a 3-inch aluminum cube. The cube and rod were driven into the ground until the cube rested flush on the soil's surface. The soil around the cube was wetted and compacted to enhance the coupling of the cube to the soil and the accelerometer was then mounted to the top of the cube. The mounted accelerometer is shown in Figure 4.

For the vibration measurements taken from the building itself, the accelerometer was mounted in a ventilation space on the south wall of the house using wax, 40 inches from the west side of the south study wall of the building and 20 inches above the ground. The setup is shown in Figure 5.

2. Results

Figure 6 compares the electrical noise found in the lab, and the noise found on site. As expected, the noise levels are very low, at approximately $4e10^{-11}$ g^2 above 35 Hz in both cases. The noise levels under site conditions are comparable to those found in the lab. We can conclude that the instrumentation is not sufficiently sensitive to pick up any differences between the floor noise in the lab and the ground noise on site. Peaks in the power spectrum found in the site vibration noise measurement at approximately 14 and 27 Hz could be caused by vibration sources specific to this site.

When an accelerometer was mounted on the aluminum block in the soil, one would expect to see some differences between measurement of the ambient background vibration measured in the soil when compared to those measured with the tripod setup. Comparison of the ambient ground vibration with the noise level of the measurement system on site is shown in Figure 7. The ground noise is nearly identical to the electrical noise in the system, which shows us that vibrations at this site are very low-level, and comparable to the electronic noise floor in the vibration measurement system. The spike at 60 Hz in the ambient ground vibration power spectrum is most likely caused by a nearby power source.

However, differences between the on site vibration floor and the vibrations picked up in the structure itself are more obvious. Although also very low-level, the vibrations measured with the wall-mounted accelerometer are about 20 times as large as the noise floor. Figure 8 indicates that the measured wall vibrations above 6 Hz are at least detectable by these instruments.

C. Impact Tests

An impact test is one of the most simple and common forms of vibrations testing. The impulse produced by an impact excitation is a short duration transient that excites a broad frequency band. The measured response resulting from a hammer impact lets one determine how, in this case, the structure or soil responds to the known excitation.

1. Experimental equipment and procedure

The same data acquisition equipment was used in the impact tests as in the ambient noise tests. However, one channel on the module was used for the input signal (the hammer), and one for the accelerometer. The windowing function used to minimize leakage was changed from a Hanning window to a Force-Exponential window.

A PCB model 086C50 impact sledge hammer was used to strike the soil next to the house and the sidewalk on the south side of the inn. The hammer weighed approximately 12 lbs. and had a 3-inch diameter steel head. A short length of MicroDot cable was attached to the hammer and then connected to approximately 30 ft. of coaxial cable. The hammer tip designated by the manufacturer as “super soft” was used for the impact tests. A total of 10 impacts were measured and the data then averaged to account for variability in the individual impacts. The hammer used in the test is shown in Figure 9.

2. Results

In the impact tests, the power spectra, relating the amplitude of the acceleration response as a function of frequency; and the time-histories, showing the acceleration response as a function of time, were recorded for each of two tests. One of the tests was conducted with the impact applied to the soil beside the house. Another test was conducted with the impact applied to the sidewalk slightly further away from the house.

Figure 10 shows the differences between the dirt and concrete impact power spectra, as well as the ambient ground vibration -- the accelerometer response without any forced excitation. The differences in spectra shape are due to the different damping characteristics of the dirt versus the concrete and the location of the hits. A diagram of the impact locations is shown in Figure 11.

Figures 12 and 13 show the differences between the time histories of the impulses, and compare the two impulses to their respective responses. As expected, the concrete impulse had a much sharper peak and its acceleration response decayed more quickly than the that of the soil impact. Although the soil impulse was in closer proximity to both accelerometers, the stiffness of the concrete allowed a force of higher magnitude, and therefore an impulse response about double of that created by the impact to the soil. In both cases, the acceleration responses lasted approximately 10 times longer than the hammer impulses.

D. Tests using vehicle excitation

It is suspected that the cause of structural damage to the Institute has been related to vibration caused by traffic on the access road to the Fechin Inn, which is located less than 25 feet from the main building of the Institute. The vibration data obtained from a vehicle passing by the Institute can be determined by taking samples of the accelerometer response caused by vehicles travelling on the access road. In this test, a variety of data were measured, including vibrations caused by vehicles ranging from a small Minivan to a large delivery vehicle. The day before the data was taken, a new layer of gravel had been added to the road. This layer of loose gravel absorbs shock and may have changed the results that would have been obtained had the gravel not been there. Due to the variation in testing conditions from the road conditions that had previously existed, results obtained through this test are only qualitative.

1. Experimental equipment and procedure

The data acquisition system and cable were identical to those used for the ambient vibration tests. However, the manual arm feature in the HP software was used, allowing the data acquisition system to take measurements when manually triggered as a vehicle was driving by. The first excitation source was a large milk delivery truck, the second a package delivery vehicle, and the third, minivan. In each test case, except the van, only one time-history was measured. In the case of the van, 10 time-histories were measured and the data averaged. The van was going at approximately 20 mph and had a weight of 5040 lbs. The weights and speeds of the other vehicles were unknown.

2. Results

The measured acceleration responses both on the ground and on the structure caused by vehicle excitation, as compared to the background levels of vibration are shown in Figures 14 -18. It was not possible to compare the acceleration response on the structure when the milk truck was the excitation source since the data was inadvertently not taken. On average, all vehicles produced increased levels of vibration on the ground and on the structure as compared to the ambient levels of vibration.

III. CONCLUSIONS

It can be shown definitively that the adobe structures and the surrounding soil at the Fechin Institute are being subjected to increased vibration levels from the monitored traffic.

The primary limitation of the study is that the largest vehicle excitation source monitored was a medium sized delivery vehicle of which the weight and speed were unknown. Therefore, there has been no testing to find a suitable upper bound to the levels of excitation caused by earth-moving and construction vehicles, the vehicles believed to have caused the onset of soil compaction and/or structural damage. Another limitation is that fact that no study has been undertaken to determine allowable vibration levels for the structures. Without such information, it is difficult to quantify the damaging effects of the measured traffic-induced ground vibration. Finally, the gravel that was added to the road surface on the day before the test most likely changed the vibration levels that would have been measured had the gravel not been present.

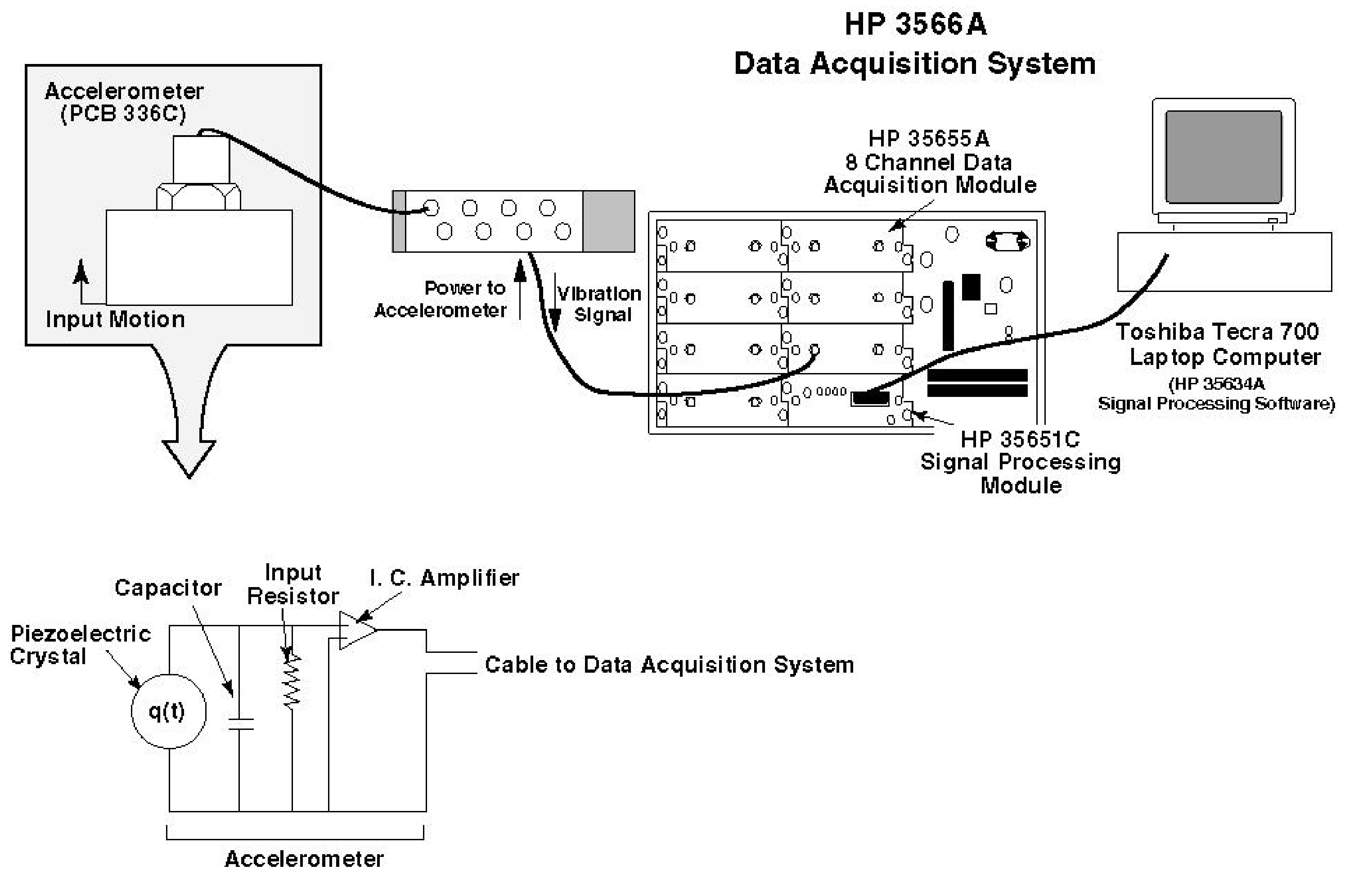

Fig. 1. Schematic diagram of the vibration measurement system.

Figure 2. Vibration Measurement and Data Acquisition System

Figure 3. Noise Floor Tripod Setup

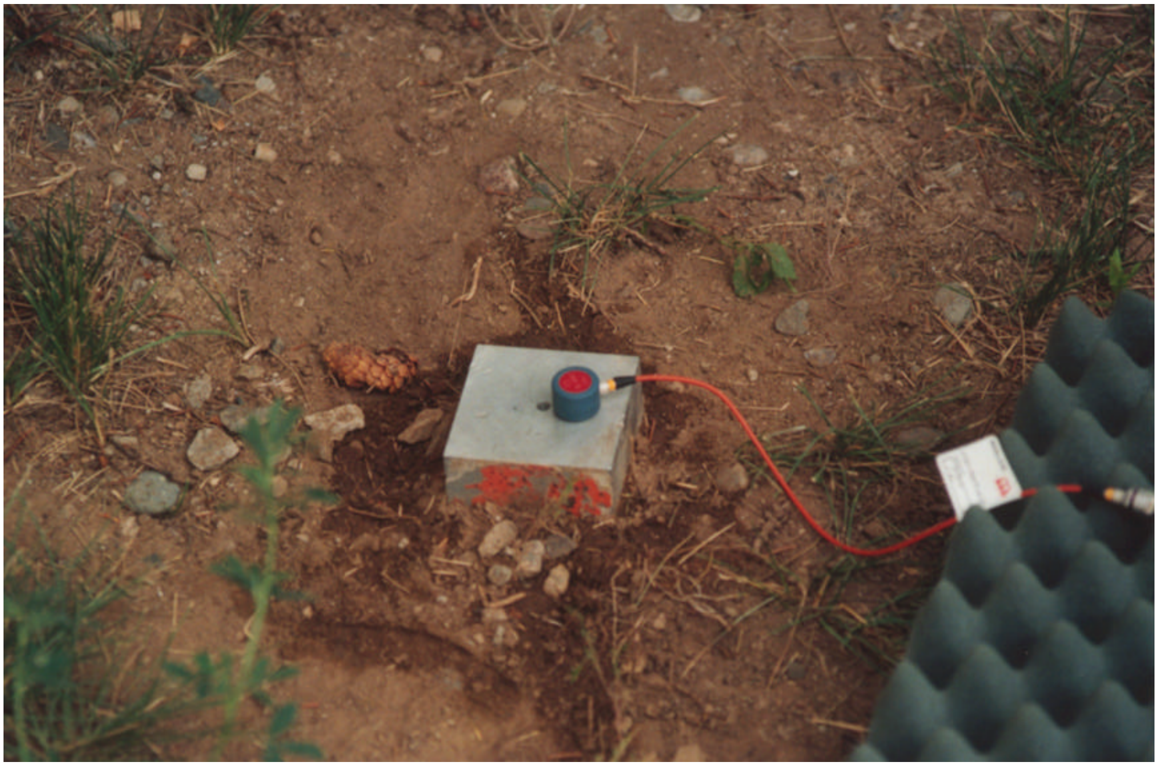

Figure 4. Mounted Accelerometer for Ground Vibration Measurement

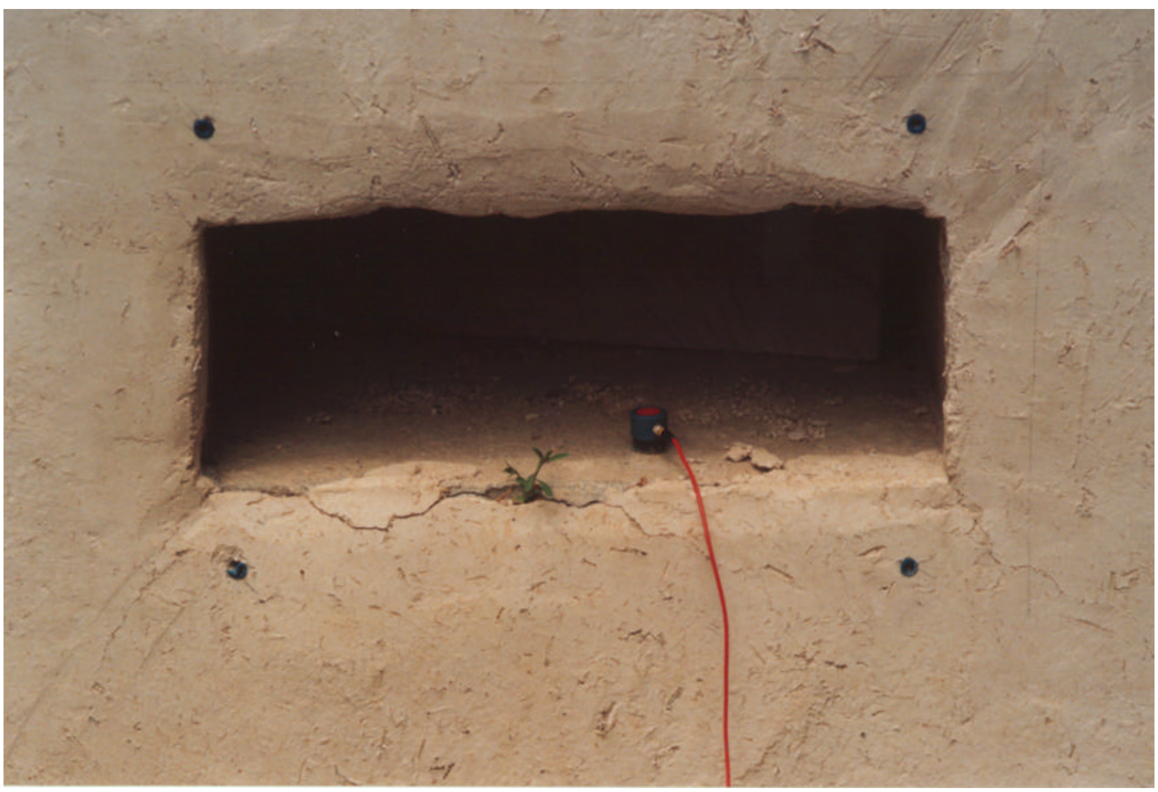

Figure 5. Mounted Accelerometer for Wall Vibration Measurement

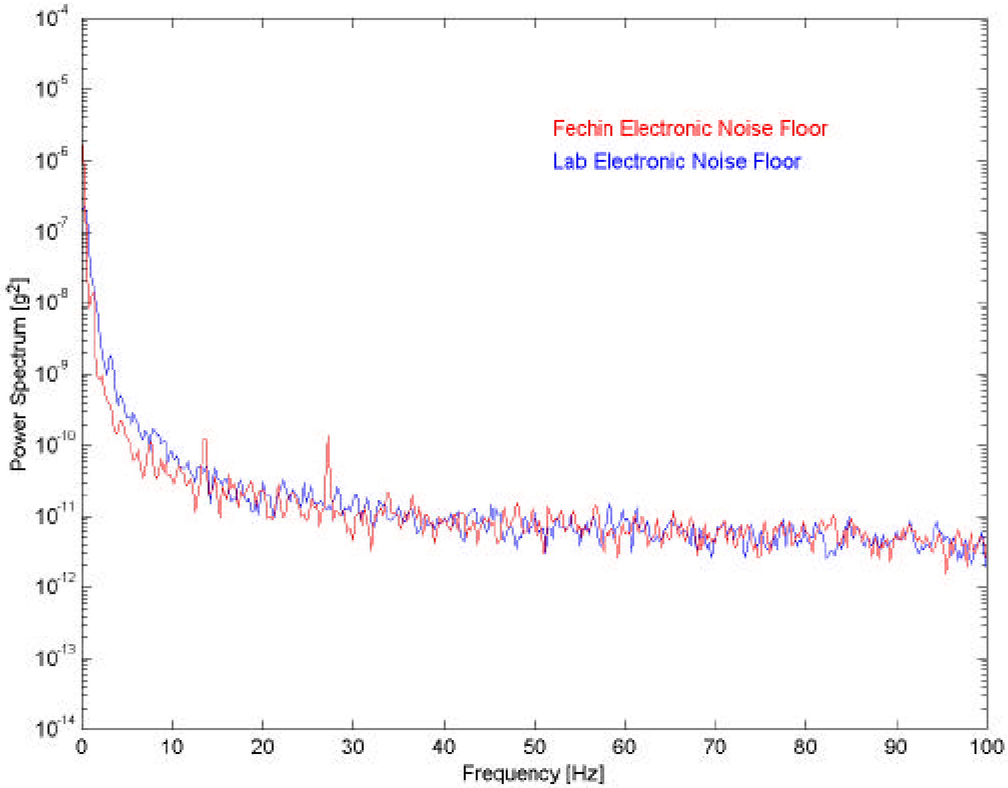

Figure 6. Electronic Noise Floors in the Lab and at the Fechin Institute

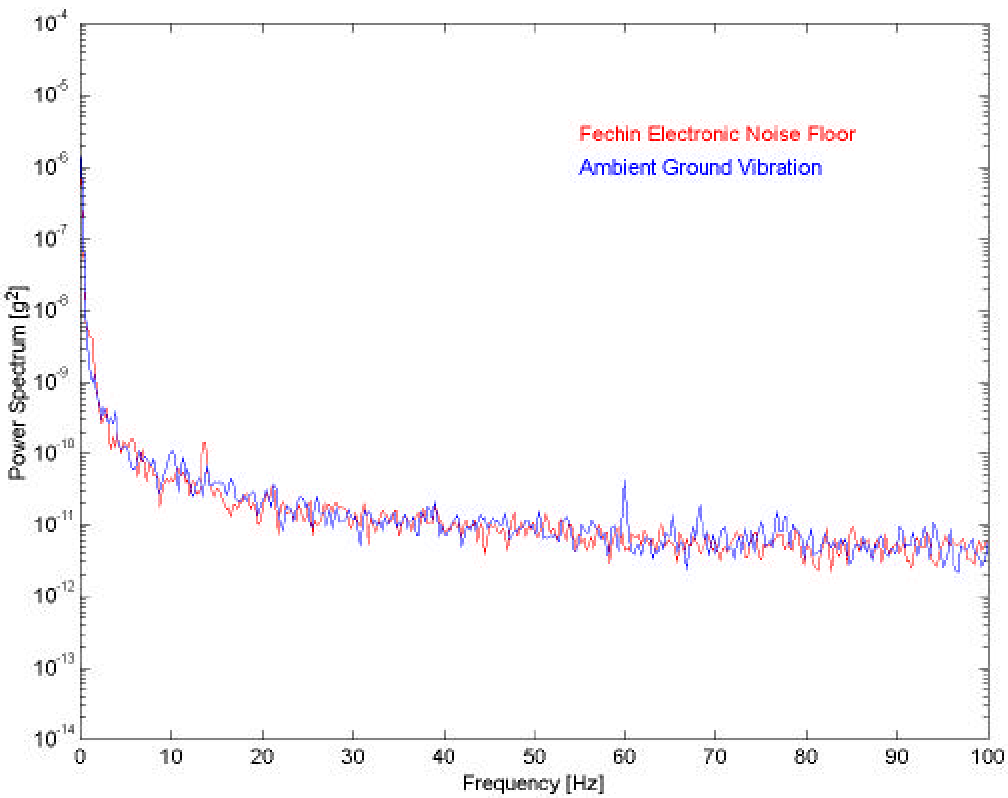

Figure 7. Electronic Noise and Ambient Ground Vibration at the Fechin Institute

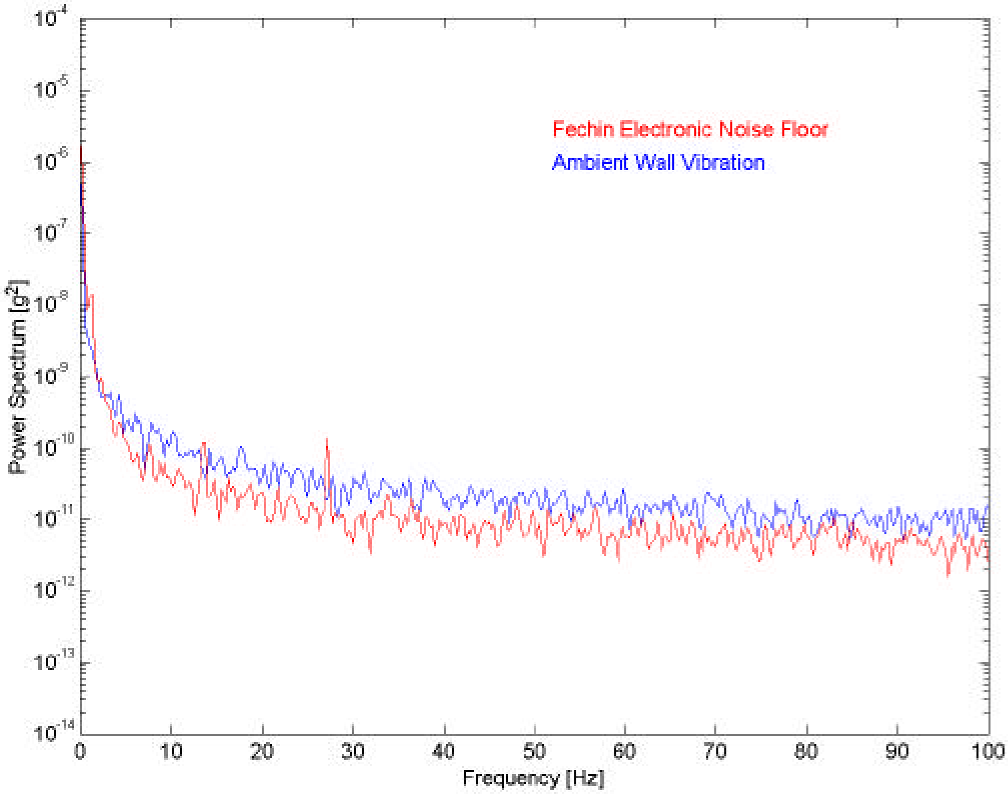

Figure 8. Electronic Noise and Ambient Structure Vibration

Figure 9. Impact Testing

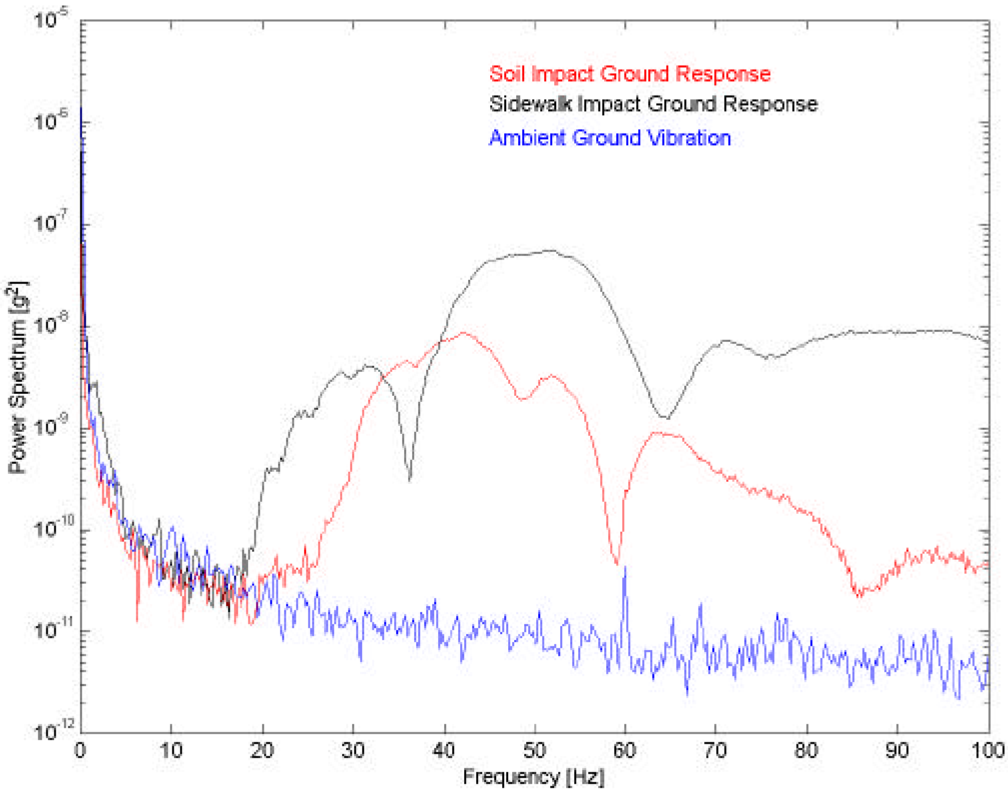

Figure 10. Ambient Ground Vibration and Hammer Impact Responses

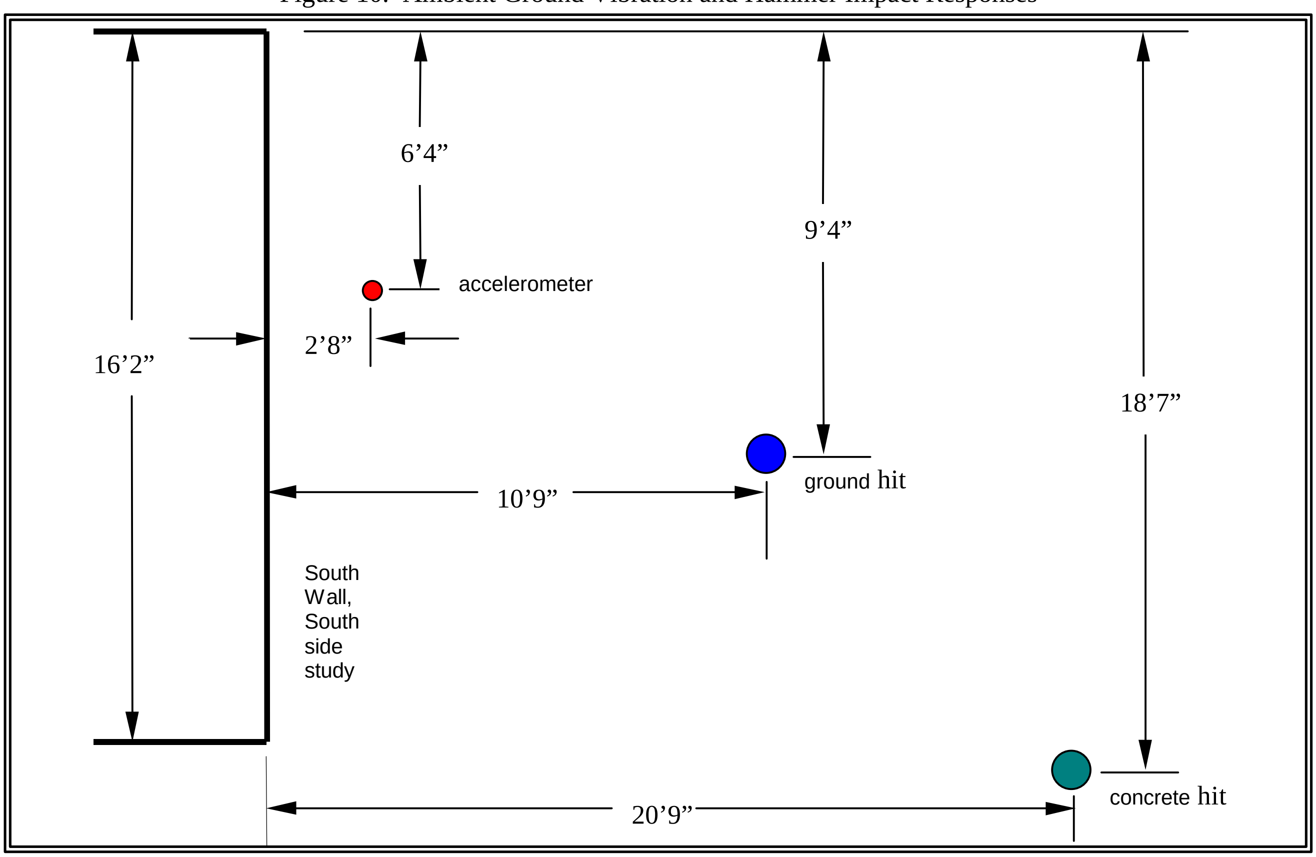

Figure 11. Impact Test Layout

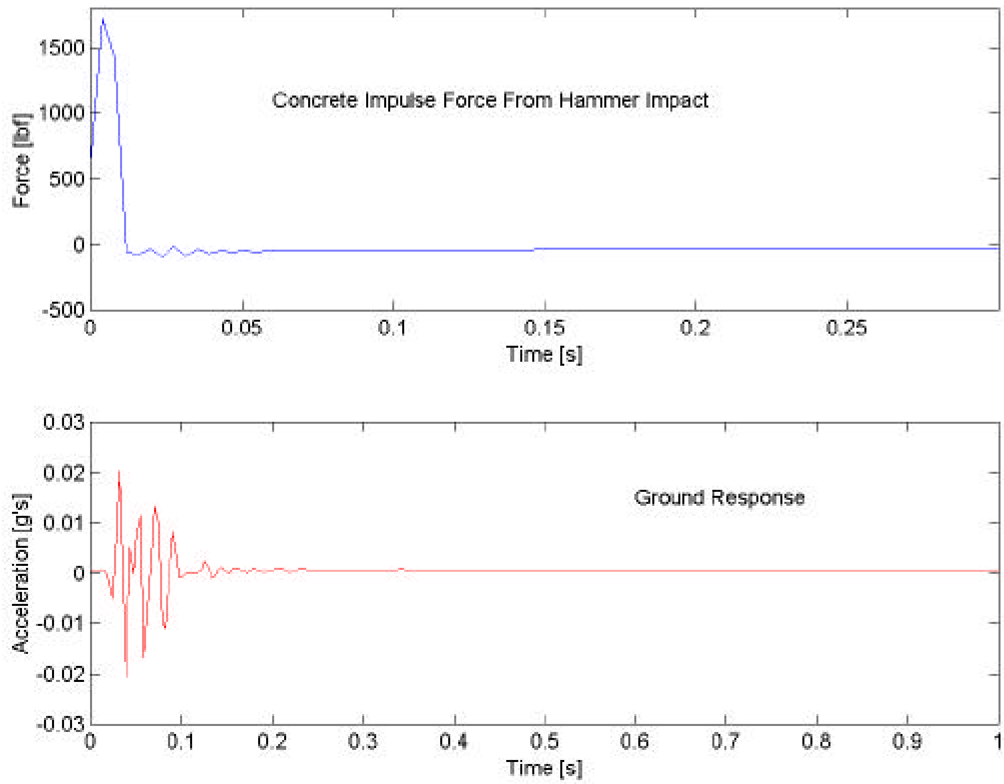

Figure 12. Hammer Impulse on Concrete and Accelerometer Response

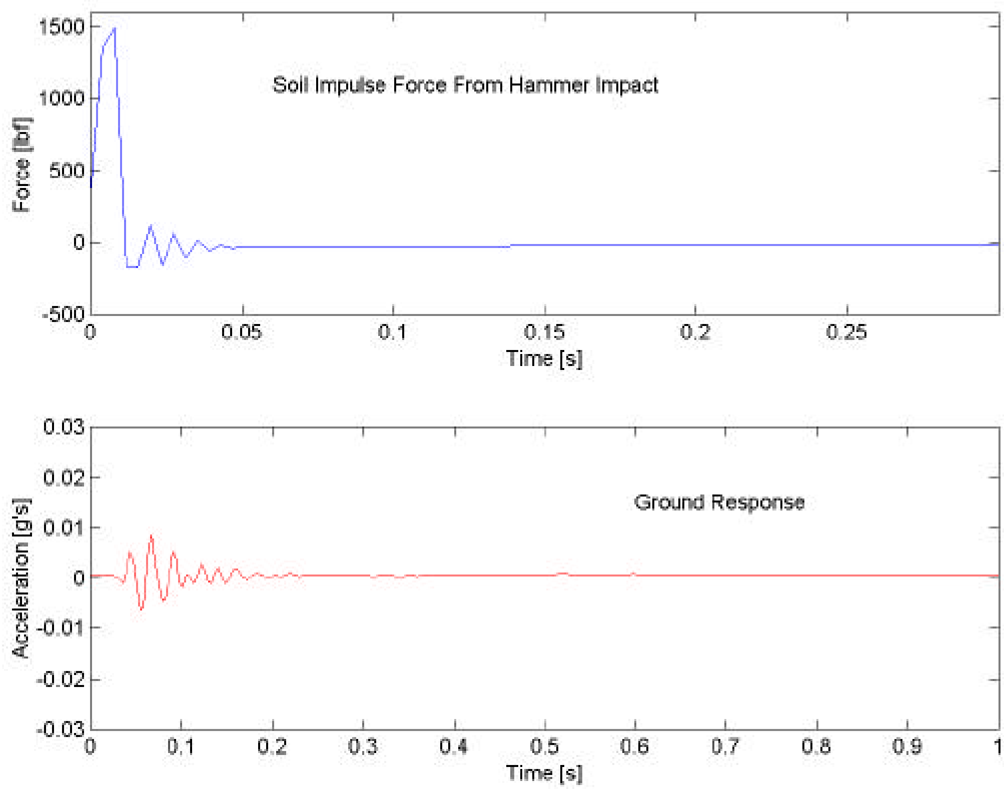

Figure 13. Hammer Impulse on Soil and Accelerometer Response

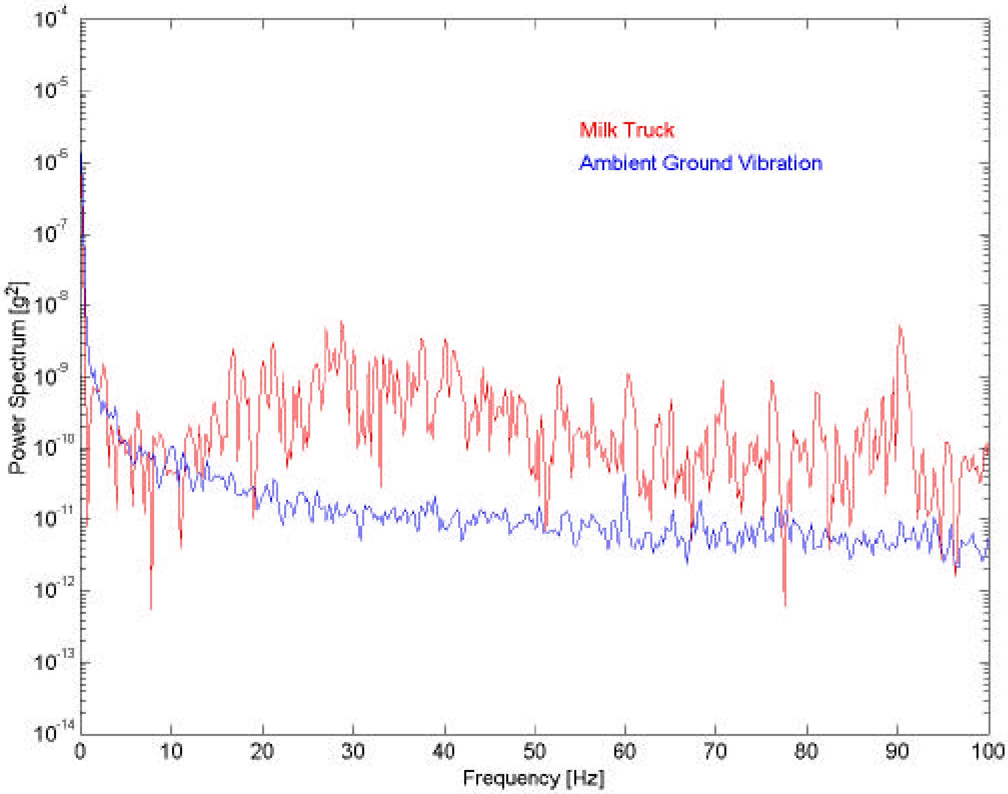

Figure 14. Ambient Ground Motion and Accelerometer Response to Milk Truck

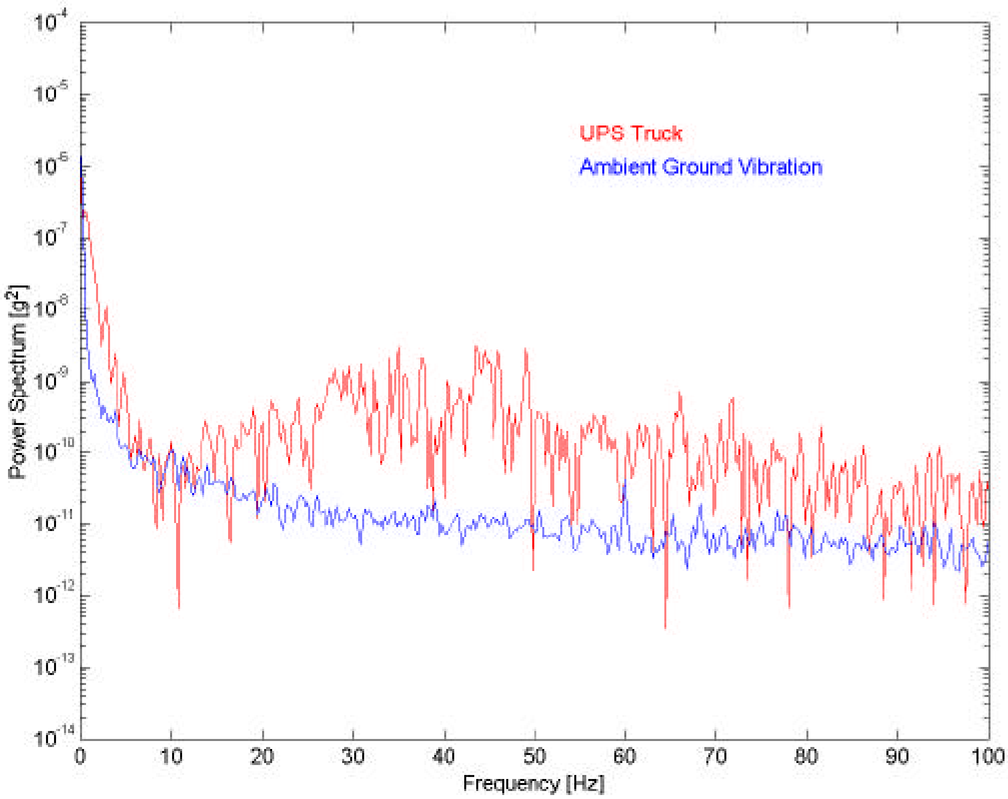

Figure 15. Ambient Ground Motion and Accelerometer Response to UPS Delivery Truck

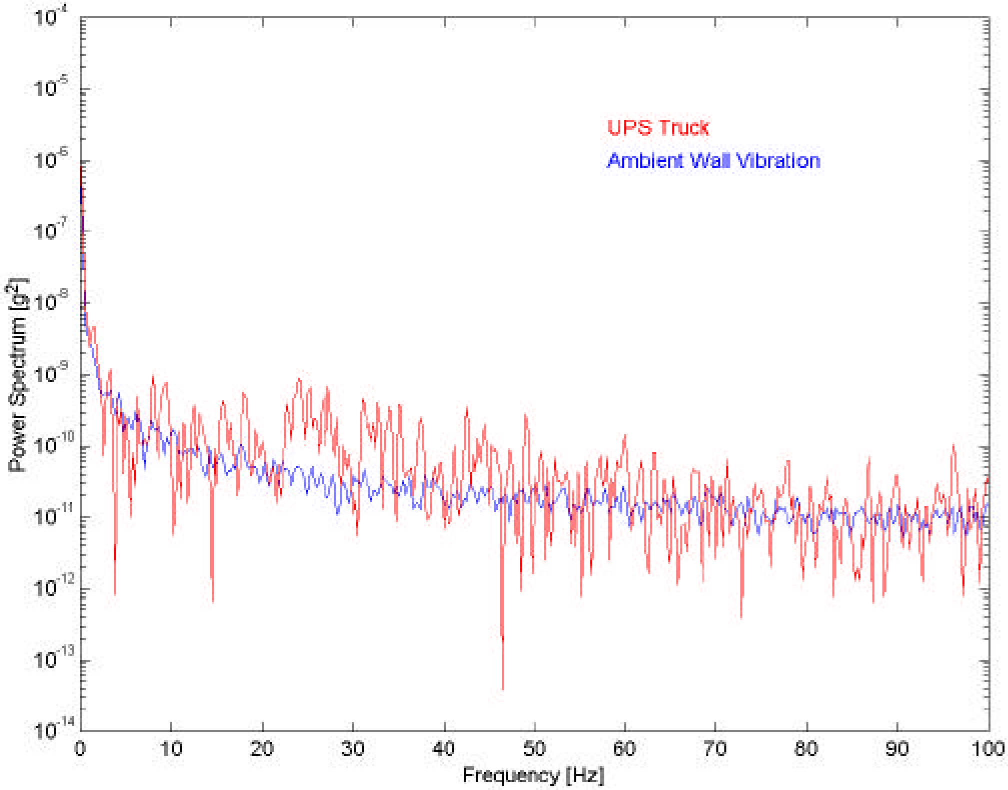

Figure 16. Ambient Wall Motion and Accelerometer Response to UPS Delivery Truck

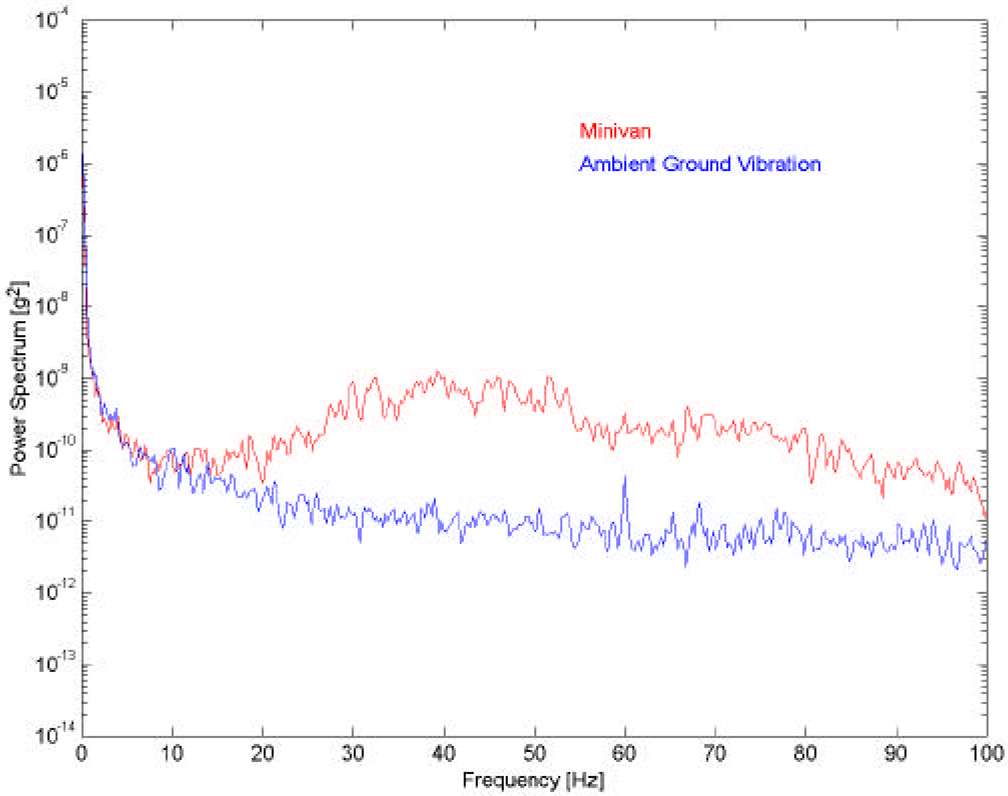

Figure 17. Ambient Ground Motion and Accelerometer Response to Minivan

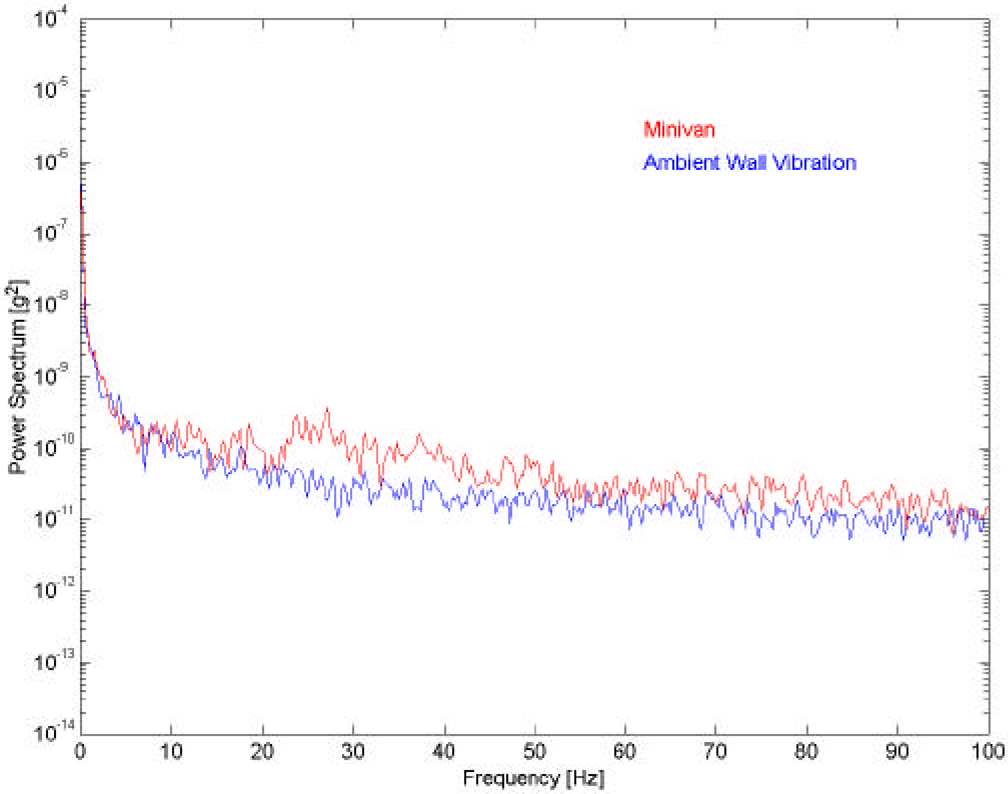

Figure 18. Ambient Wall Motion and Accelerometer Response to Minivan